M.O. 514 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 78. No. 927. SEPTEMBER 1949

DR. JOHNSON AND THE WEATHER

By D. L. BOWEN

The everyday discussion of weather is by no means a twentieth-century prerogative, for it is an historic fact that the England of Samuel Johnson's day was keen to cultivate the habit; indeed, it was in great vogue in the London of the 1770's—and how the worthy Dr. Johnson hated it.

It is hardly surprising, feeling as he did, that Dr. Johnson time and time again fell back on his superb and seemingly limitless vocabulary to quash any desire on the part of his friends to "talk" weather. We can consider that it was Johnson's profundity which caused him to regard casual weather observations as "small talk", but whatever the reasons it seems that the learned gentleman would allow no compromise; he would be as withering as his commanding presence and brilliant fluency would allow.

Boswell evidently was an aspiring amateur meteorologist, and, though frequently rebuked by his master, was never permanently cheated of his interest in weather. In his "Life of Dr. Johnson" he recorded some amusing weather repartee that took place between Johnson and himself; there is, for example, the entry for July 1763: ". . . On the 14th we had another evening by ourselves at The Mitre. It happening to be a very rainy night, I made some common-place observations on the relaxation of nerves and depression of spirits which such weather occasioned; adding, however, that it was good for the vegetable creation. Johnson, who, as we have already seen, denied that the temperature of the air had any influence on the human frame, answered with a smile of ridicule, 'Why yes, Sir, it is good for vegetables, and for the animals who eat those vegetables, and for the animals who eat those animals.' This observation of his aptly enough introduced a good supper; and I soon forgot, in Johnson's company, the influence of a moist atmosphere."

To leave his readers in no doubt whatsoever, Boswell, on a later occasion, tells another story. "There was", he declares, "no information for which Dr. Johnson was less grateful than for that which concerned the weather. . . . If any one of his intimate acquaintance told him it was hot or cold, wet or dry, windy or calm, he would stop them by saying, 'Poh! poh! you are telling us that of which none but men in a mine or a dungeon can be ignorant. Let us bear with patience, or enjoy in quiet, elementary changes, whether for the better or the worse, as they are never secrets'."

There were times, however, when Samuel Johnson's lack of compromise must have been thoroughly upsetting. On one occasion both Boswell and Johnson had enjoyed to the full an exceptionally fine day in July 1763. It had been spent on the Thames; both had enjoyed the day's sculling, although Boswell's resistance was weakened on account of his having sat up the whole of the previous night. Having overstayed the visit paid to Greenwich, they were exposed to radiation cooling as the return journey by river was undertaken, and doubtless the cold was accentuated for anyone negotiating an open boat. Johnson's " robust frame was not in the least affected " by the diurnal cooling, and Boswell, having succumbed to shivering, was sternly rebuked as though his behaviour " had been a paltry effeminacy."

Yet it would not be altogether fair to say that Johnson was not weather conscious. He found time to pause and admire the " silver flood " of the Thames as it flowed past Greenwich—and the " silver flood " of an English river cannot be divorced from the " silver flood " of English rain. No, evidence does not show him making fun of weather as such. His war was against those who, in saying the obvious things about the weather whenever the opportunity presented itself or whenever there was a gaping chasm to be filled pending the resumption of a flow of conversation, would deliberately and inevitably lose their originality. It was imaginative laziness, a thing he could not tolerate.

Even more infuriating to the very hard-working Dr. Johnson was the bodily laziness that his contemporaries would attribute to the weather rather than to themselves. In such cases many would wholeheartedly agree with the severity of Johnsonian censures, but, justifiable or not, they are most stimulating and often amusing: take, for example, the following pronouncements—they could almost be described as " laws ":—

" This dependence of the soul upon the seasons, those temporary and periodical ebbs and flows of intellect, may, I suppose, justly be derided as the fumes of vain imagination. . . . The author that thinks himself weather-bound will find . . . that he is only idle or exhausted. But while this notion has possession of the head, it produces the inability which it supposes. . . ." Cleverly expounded, one is made to feel that such invective is aimed at more than just authors who find they are incommoded by unfavourable seasonal or diurnal changes of weather. One feels that none can claim exemption from Dr. Johnson's scolding, be he business executive, farmer, newspaper editor, or meteorologist.

But anyone who takes advantage of prevailing—or anticipated future—weather conditions to harness, as it were, such phenomena to the task in question, is a man after Johnson's own heart. Boswell verifies this:—

" He records of himself this year, ' Between Easter and Whitsuntide, having always considered that time as propitious to study, I attempted to learn the Low Dutch language.' It is to be observed, that he here admits an opinion of the human mind being influenced by seasons. . . ."

Boswell was obviously thinking of the cutting remarks in an edition of the *Idler*, words that he knew had emanated from his master: " Those that laugh at the portentious glare of a comet, and hear a crow with equal tranquillity from the right or left, will yet talk of times and situations proper for intellectual performances." But the weight of Dr. Johnson's pronouncements on this

subject of weather will verify that his warfare left unscathed those who adjusted their time-tables according to the prevailing meteorological conditions so that they might thereby be more effective.

There is an aspect of the Johnson of later years that does not compare favourably with the Johnson of 1760—or even 1770. He finds he himself is indulging in that easily acquired habit, that same luxury that he denied to others—the universal practice of observing and commenting on the weather. The reason, however, requires little search, for in January 1784 he writes to his friend to inform him of his sufferings:—

" I was seized with a spasmodic asthma so violent that with difficulty I got to my own house, in which I have been confined eight or nine weeks, and from which I know not when I shall be able to go even to church. . . . My nights are very sleepless and very tedious. And yet I am extremely afraid of dying.

" My physicians try to make me hope, that much of my malady is the effect of cold and that some degree at least of recovery is to be expected from vernal breezes and summer suns. If my life is prolonged to autumn I should be glad to try a warmer climate. . . ."

How tragically ironical! The cause of Johnson's illness was presumably the weather, the result was his own extensive weather talk, and the remedy—a suggested exposure to weather of a different kind. The picture of the learned doctor takes new colour. " I am reduced to think," he says, " and am at last content to talk of the weather."

On this candid admission Dr. Johnson's past strictures must be forgiven, and the more especially when he postscripts these remarks by quoting against himself the familiar proverb, " Pride must have a fall."

RELATION BETWEEN UPPER WIND STRUCTURE AND RAINFALL AT FRONTS

By A. E. PARKER B.Sc., A.M. Tech. I.

The fact that upslope (or downslope) motion may occur at fronts is not usually used directly in forecasting, but the upslope motion is deduced from the weather and clouds associated with the front. This method of forecasting, therefore, does not deal with physical processes but is merely statistical in character. The ideal method of forecasting would be to use physics to indicate when and where upslope motion will occur and then to deduce the resulting weather. However, this method is not possible at present and, indeed, it is by no means certain that it will ever become possible.

The object of this note is to show that upslope motion at fronts can be detected by using the results of upper wind soundings, and can be taken directly into account in forecasting. The writer has been using the technique outlined in this note for the last two years or so and has found the method of great help in forecasting. By using the method, the forecaster not only obtains a very clear picture of wind structure at fronts but it sometimes enables outbreaks of rain, ahead of apparently weak warm fronts and behind cold fronts, to be forecast where none previously existed.

It is believed that the method will be new to the majority of forecasters in the British Isles.

Vertical wind structure through a warm front.—Suppose that we have an upper wind sounding which passes through a warm-front surface, and we wish to examine the upslope (or downslope) motion, if any, which is occurring. Upper winds from the sounding are plotted on a hodograph and a line is drawn through the origin of the hodograph parallel to the direction of the surface warm front at the point nearest to the upper wind station. The wind hodograph has been described frequently in the meteorological press during recent years and probably needs no introduction to readers of this magazine. However, the examples should make it and its use quite clear. Now the component of the wind at right angles to the surface direction of the front will be termed the " normal wind ". A little thought will show that,

(1) if the normal wind increases with height above the frontal surface then upslope motion must be occurring ;

(2) if the normal wind does not change with height then no upslope motion is occurring; and

(3) if the normal wind in the warm air decreases with height then the warm air is subsiding down the frontal surface. This type of motion is quite common at the top of the cold dome.

Vertical wind structure through a cold front.—The results of an upper wind sounding passing through a cold front surface are plotted on the hodograph in the same way as for a warm front but in this case,

(1) if the normal wind in the warm air decreases with height then upslope motion is occurring and we have a cold front with a wide band of rain and cloud behind it;

(2) if the normal wind does not change with height through the frontal surface then no upslope motion is occurring. It should not be deduced from this, however, that the front will give no precipitation. This type of front usually gives rain ahead of it due to convergence, and possibly instability, in the warm air; and

(3) if the normal wind increases with height through the frontal surface then the warm air is subsiding down the cold-front surface. The increase of wind with height in the warm air with this type of front is sometimes very marked indeed, and then the cold front gives no precipitation and only some strato-cumulus cloud ahead of it. These fronts are usually fast-moving fronts.

Upper wind soundings well ahead of cold fronts can be used to deduce the variation of the normal wind with height through the frontal surface. For example, the normal wind will commence to decrease with height at 500 mb. up to 200 miles ahead of a cold front having upslope motion of the warm air above it.

Frontal speed from the hodograph.—It is obvious that the speed of a warm front is the speed at which the cold air ahead of it is moving. Therefore, the speed of a warm front will be the normal wind at the base of the mixing zone and will be independent of height if the front is not changing its slope. The height of the base of the mixing zone can be obtained from a tephigram if a temperature sounding was made at the same time as the wind sounding; or, failing this, it can be obtained from the hodograph because the wind-shear vector for the winds at the top and bottom of the mixing zone is parallel to the surface front. Using this method to find the speed of a warm front the

writer has, at times, obtained the speed of the front to within one knot of the actual speed. The method is to be preferred to that of using the geostrophic scale and then guessing a fraction!

Practical examples of the use of the hodograph.—In the hodograph charts the radial scale is one division to 20 kt.; the winds at 900, 800 . . . mb. levels are represented by vectors from the origin to the points marked 9, 8 . . . respectively; the lines drawn on the hodographs represent the shear vectors between levels; and the arrow-heads at the ends of radii show the direction from which the corresponding wind is blowing.

Fig. 1—0600 G.M.T., August 8, 1946.—At 0600 a warm front was lying from 51°N.5°W. to the Channel Islands to 49°N.3°E. The hodograph of the Larkhill winds shows a normal wind increasing rapidly with height indicating upgliding motion of the warm air along the frontal surface. This front gave 0·40 in. of rain at Boscombe Down. The increasing normal wind was well marked to 400 mb. indicating that a thick layer of warm air was taking part in the upgliding motion. The intensity of rainfall from this front would have been expected to increase as the front moved north-eastwards and a deep layer

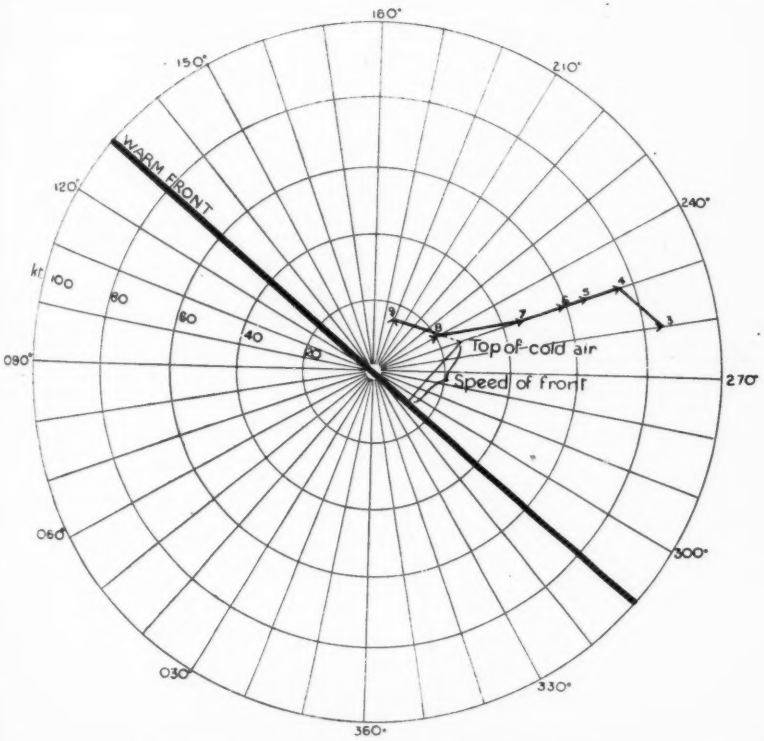

FIG. I—HODOGRAPH OF WIND OVER LARKHILL, 0500, AUGUST 8, 1946

of air became saturated. Young waves on cold fronts must have a similar wind hodograph just ahead of them which accounts for the large rainfall often associated with small waves.

Now refer to the hodograph again. It will be seen that there is a well marked wind discontinuity between 800 and 700 mb., and by producing the wind-shear vector between the winds at 900 and 800 mb. to meet the 250° radial line we find that the speed of the front is 23 kt.

Fig. 2—1100 G.M.T., August 24, 1946.—A cold front at 1200 extended from Liverpool to Swansea to St. Eval. The hodograph of the Liverpool winds shows a normal wind decreasing with height from 800 to 500 mb. and therefore considerable rain would have been expected behind the front. Moderate to heavy rain fell as the front passed Shawbury (near Shrewsbury) followed by moderate to slight rain. The total rainfall at Shawbury from this front was 0·31 in., with 0·20 in. in three quarters of an hour. The pressure rose 6 mb. in three hours behind the front, which is interesting since rising pressure is not usually associated with moderate rainfall; but it is typical of this type of cold front due to marked advection of cold air.

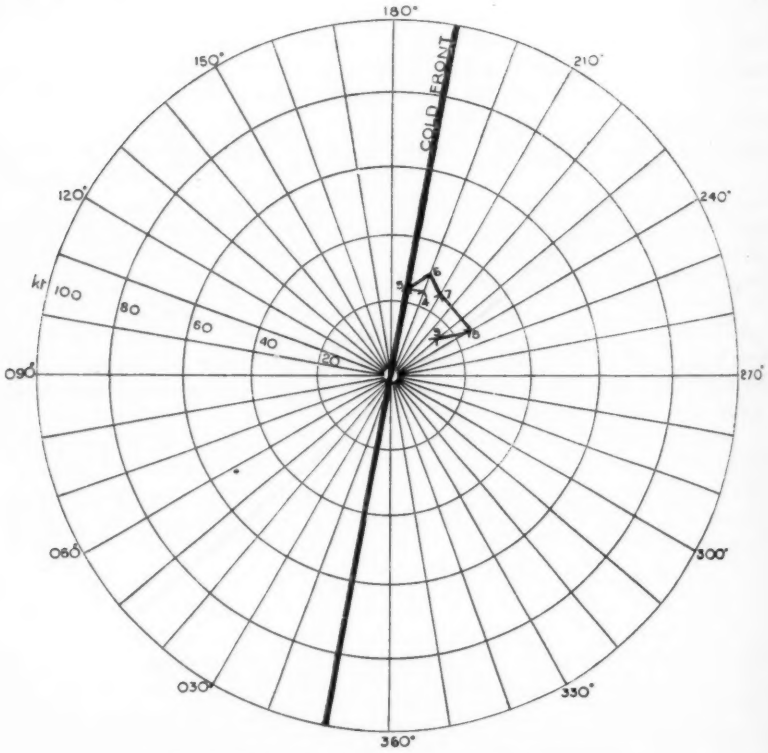

FIG. 2—HODOGRAPH OF WIND OVER LIVERPOOL, 1100, AUGUST 24, 1946

This example illustrates how an outbreak of rain behind a cold front can be forecast. If the warm air above a cold-front surface is moist and convectively unstable and the normal wind decreases with height through the frontal surface, then a widespread outbreak of moderate to heavy rain behind the front is almost certain and may extend up to 150 miles behind the cold front.

Fig. 3—0500 G.M.T., September 18, 1946.—At 0600 a warm front was 230 nautical miles south-west of Liverpool and lying north-west to south-east. This is a very interesting case. A forecaster, after looking at the 0600 chart, would almost certainly have said that the front would give continuous moderate rain as it moved north-eastwards across the country. The pressure had fallen 6·2 mb. at Shannon and Cork in south-west Ireland and 2·6 mb. in three hours at St. Eval in Cornwall. Furthermore, the upper winds veered and increased very rapidly with height indicating a marked temperature difference between the cold and warm air masses. The hodograph of the Liverpool winds suggests, however, that the upgliding motion at the front was confined to the layer 600 to 500 mb., *i.e.* a somewhat shallow layer above the frontal surface. The upper air over Liverpool above the frontal surface was also stable (*i.e.* had a lapse rate less than the saturated adiabatic) so that, taking all the facts into

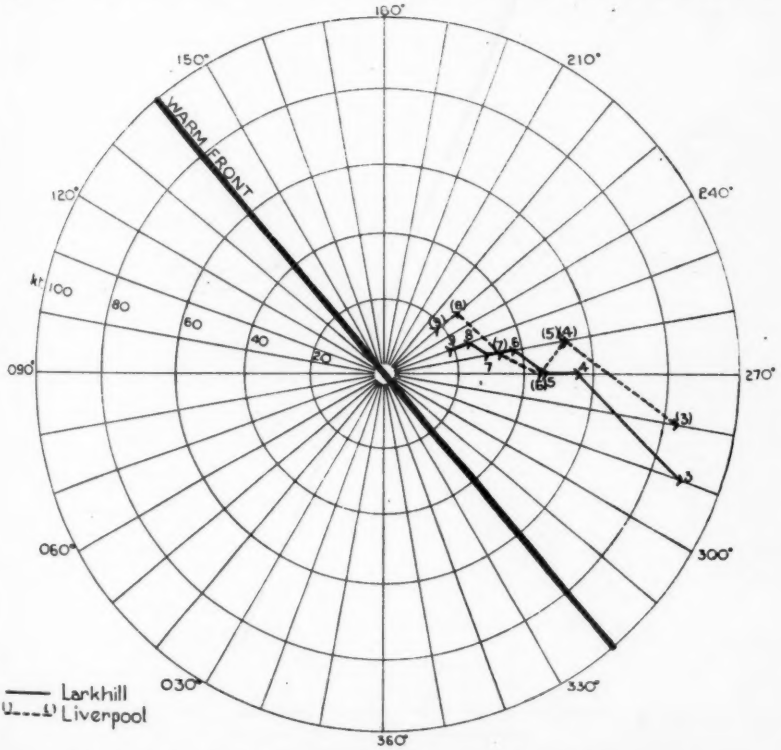

FIG. 3—HODOGRAPH OF WIND OVER LARKHILL AND LIVERPOOL, 0500, SEPTEMBER 18, 1946

consideration, one would not have expected much rain in the Liverpool area. This deduction was confirmed as only a trace of rain was recorded at Shawbury. Mr. C. K. M. Douglas* has pointed out that a dry patch of air is common to the lee of the Welsh hills due to orographic effects, but this does not affect the truth of the deductions made from the hodograph.

The hodograph of the Larkhill winds tells a different story, however, as the normal wind was increasing with height from 700 to 400 mb., and this suggests upgliding motion of the warm air through a rather deep layer, and hence the possibility of considerable rain. Stations in the south of England mainly reported continuous slight to moderate rain as the front approached. This was rather unusual as a warm front usually gives its greatest rainfall towards the tip of the warm sector.

The hodograph for the Liverpool winds shows a well marked wind discontinuity between 600 and 500 mb., so we may take the top of the cold air over Liverpool at 600 mb. The normal wind at this level is 35 kt. and this is

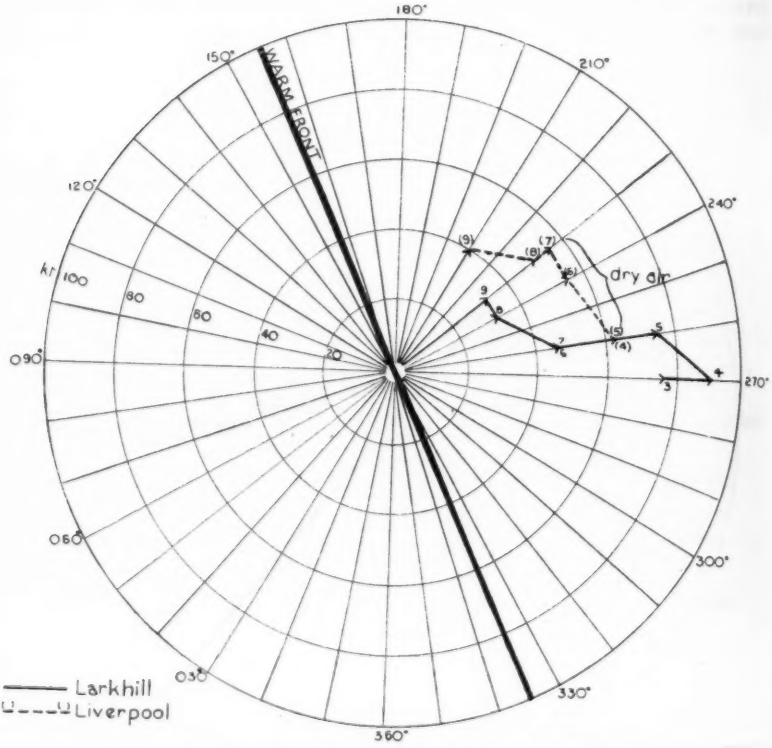

FIG. 4—HODOGRAPH OF WIND OVER LARKHILL AND LIVERPOOL, 1100, SEPTEMBER 18, 1946

*DOUGLAS, C. K. M.; Rainfall from above 6,000 ft. in relation to upper winds and fronts. *Quart. J. R. met. Soc., London*, **62**, 1936, p. 207.

[*To face page* 252

O.W.S. *Weather Watcher* AND *Weather Recorder* AT OCEAN WEATHER SHIPS' BASE AT GREENOCK

OCEAN WEATHER SHIP ENSIGN

During the early days of their existence the British ocean weather ships flew the red ensign, but it has recently been considered more fitting that, being Government ships, they should fly a blue ensign defaced with an appropriate badge, as is customary for other vessels of similar category. The new ensign, as illustrated, was hoisted aboard the *Weather Watcher* and *Weather Recorder* at Greenock on March 7, 1949, the ceremony being performed by Provost Morris of Greenock

To face page 253

CIRRUS INDICATING RATHER UNSETTLED WEATHER AHEAD IN TANGANYIKA

This type of sky, which was photographed near Lushoto late on a November morning is rather persistent and may sometimes indicate a more unsettled period of weather ahead. On this particular occasion the deterioration may well have been associated with the "short" or "grass rains" which mark the southward migration of the potential zone of convergence which exists between the régimes of the two "monsoons" which affect Kenya and northern Tanganyika. Lushoto is situated among the Usambara Mountains about 50 miles inland from the coast of northern Tanganyika and connected by the Pare Mountains to Kilimanjaro 140 miles to the north-north-west

clearly the speed of the front. The Larkhill wind hodograph indicates a double wind discontinuity (*a*) from 500 to 400 mb. and (*b*) from 700 to 600 mb., probably indicating a double frontal structure. However, since the winds were only reported to the nearest whole ten degrees the double structure is not certain from the hodograph but was confirmed by the upper air ascents. It will be noticed that the normal wind at the 500-mb. level is 35 kt. which is the same as was given by the Liverpool winds.

Fig. 4—1100 G.M.T., September 18, 1946.—At 1200 the warm front considered in the previous example had moved to a position just west of Liverpool and just east of Larkhill. The actual speed of the front works out at 38 kt. as compared with the hodograph value of 35 kt. This discrepancy is no doubt due to the fact that the winds are reported at intervals of 50 mb. and the top of the cold air was somewhat higher than the value actually taken. The air above Liverpool was still very dry from 700 to 400 mb. with humidities varying from 37 to 20 per cent. Slight upslope motion of the warm air is suggested from 900 to 700 mb. Upgliding motion of the warm air along the front through a deep layer is suggested in south-east England by the Larkhill wind hodograph, as the normal wind was increasing markedly with height from 800 to 400 mb. Furthermore,

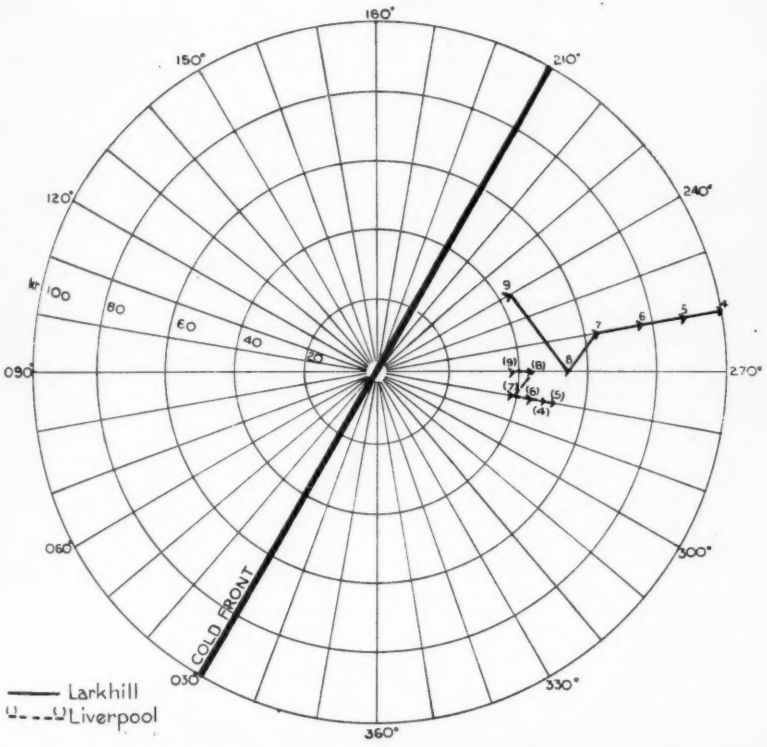

FIG. 5—HODOGRAPH OF WIND OVER LARKHILL AND LIVERPOOL, 1700, SEPTEMBER 18, 1946

the air was moist at all levels to 400 mb. showing that lifting must have taken place, and thereby confirming the deductions made from the 0500 hodograph.

Fig. 5—1700 G.M.T., September 18, 1946.—At 1800 a cold front extended from just east of Liverpool to Fairwood Common (near Swansea) and thence to the Scilly Isles. This cold front was the one associated with the warm front discussed in the two preceding examples. The normal winds on the Larkhill ascent increase with height at all levels and the air was very dry above 700 mb. A normal wind increasing with height through a cold-front surface indicates subsidence of the warm air and hence dryness. The Liverpool wind hodograph indicates a normal wind increasing with height except in the layer 800 to 700 mb. and this suggests the possibility of a layer of cloud at this level. It is worth noting here that a mere inspection of the hodograph frequently enables the moist and dry layers to be located. In fact, on one occasion in Germany, it was possible to obtain from the hodograph the height and thickness of a medium cloud sheet only about two to three thousand feet thick.

Fig. 6—0500 G.M.T., November 23, 1946.—At 0600 a warm front was 315 nautical miles west-south-west of Larkhill, which would give the top

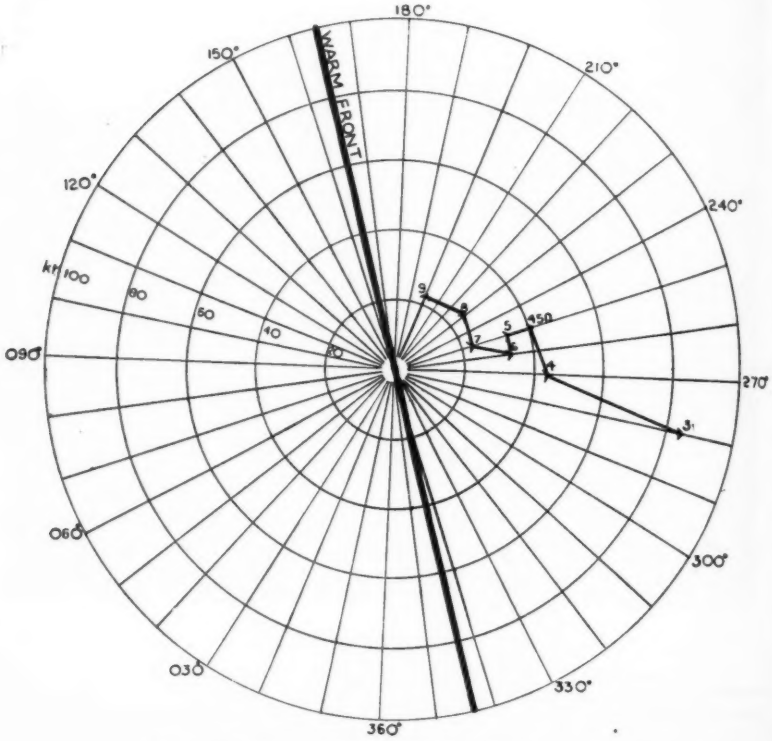

FIG. 6—HODOGRAPH OF WIND OVER LARKHILL, 0500, NOVEMBER 23, 1946

of the cold air over Larkhill at between 700 and 600 mb. The normal wind was increasing markedly with height above 700 mb. so we should have expected considerable rain from the front. This result was confirmed, as the front gave considerable rain in the south of England.

Fig. 7—1100 G.M.T., November 23, 1946.—At 1200 the cold front associated with the warm front discussed in the previous example was lying from 53⅔°N.8½°W. to 50½°N.10°W. to 47°N.14°W., *i.e.* just east of Valentia. The hodograph of the Valentia winds shows a normal wind increasing with height at practically all levels from 900 mb. to 400 mb. except in a shallow layer from 700 to 600 mb. This increasing normal wind indicates subsidence of the warm air down the cold-front surface and we should, consequently, expect the air to be dry, especially above 600 mb. This dryness of the air was confirmed by the reported humidities which were very low indeed above the 600-mb. level. This being so, the rain from the preceding warm front would be expected to die out in the area downwind from Valentia. This deduction was justified, as the rain in the Irish sea and the north of England, ahead of the preceding warm front and occlusion, soon ceased. At this stage a forecaster might have been tempted to forecast that the rain would die out all along the warm front.

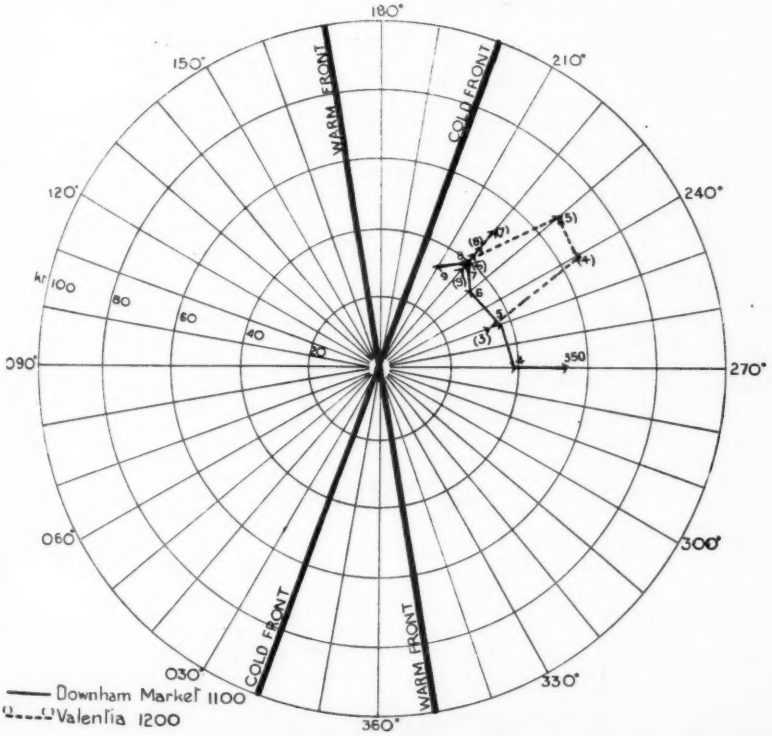

FIG. 7—HODOGRAPH OF WIND OVER DOWNHAM MARKET AND VALENTIA, NOVEMBER 23, 1946

However, this would have been incorrect as the warm front continued to give considerable rain in the south of England for some time, which shows that the warm air well to the south of Valentia had not subsided down the cold-front surface.

This example was discussed to illustrate the sudden development of subsiding motion down the cold front surface between 0500 and 1200 and illustrates a useful rule; if a warm front is active, *i.e.* the normal wind increases markedly with height, it will be followed by an inactive cold front. This rule holds the closer one approaches the tip of the warm sector. It clearly no longer holds at points along the cold front well away from the tip of the warm sector where the cold front is inclined at a small angle to the warm-sector isobars.

Wind discontinuity at the front and vertical velocity from the hodograph.—The hodograph can be used to obtain the wind discontinuity at a frontal surface, and then the vertical velocity of the warm air follows at once if the frontal slope is known.

Using the data contained in Fig. 1, Hodograph of wind over Larkhill on August 8, 1946, let us plot the normal wind in knots against the height in thousands of feet as in Fig. 8. It will be seen that the values of the normal wind

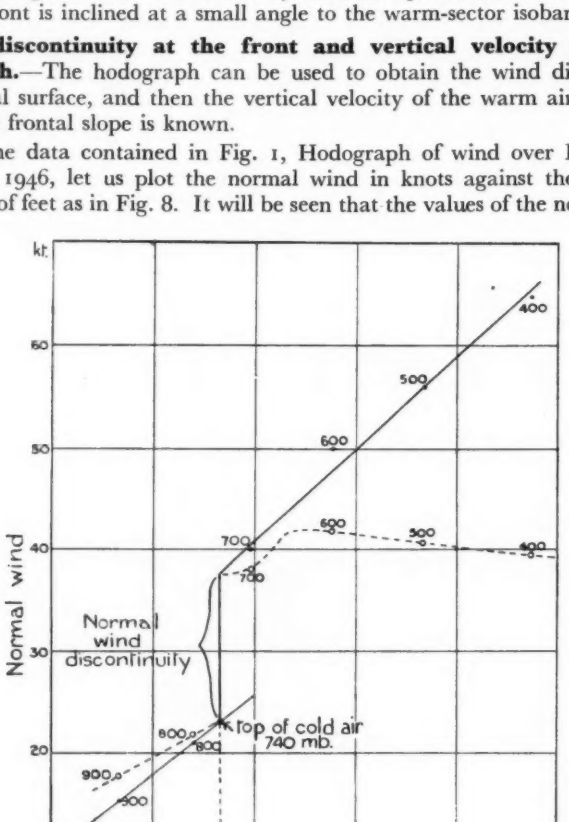

FIG. 8—RELATION BETWEEN NORMAL WIND AND HEIGHT

for the region 700 to 400 mb. lie on a straight line. If we produce this line back to the height corresponding to the top of the cold air, *i.e.* 8,400 ft. (740 mb.), we obtain the normal wind at this height in the warm air. The top of the cold air was obtained from the hodograph, Fig. 1, and is the height corresponding to a normal wind of 23 kt. The two values of the normal wind are thus:—

	kt.
Normal wind in the warm air (at 740 mb.) ..	$37\frac{1}{2}$
Normal wind in the cold air (at 740 mb.) ..	23
Wind discontinuity	15 approximately.

This shows that the warm air has a vertical velocity of $w = 15 \tan A$, where A is the angle of slope of the front. If two upper air ascents are available at different distances from the front then its slope can be obtained fairly accurately and the vertical velocity of the warm air computed.

Let us now weight the normal wind given in Fig. 8 with density, using the weighting formula;

$$\text{Weighted normal wind (at } p \text{ mb.)} = \frac{\text{Normal wind} \times \text{density (at } p \text{ mb.)}}{\text{density at 740 mb.}}$$

The results of these calculations are shown on Fig. 8 by the broken line. It will be seen that the weighted normal wind is practically constant with height. This suggests that the flow of the warm air in this case was practically two-dimensional and that the stream-lines were lines parallel to the frontal surface.

Rainfall estimates from hodograph analysis.—If u is the normal wind in the warm air at some level and u_f the speed of the front, then w, the vertical velocity of the warm air at the level where the normal wind is u, is given by

$$w = (u - u_f) \tan A.$$

If A is not known exactly tan A may be taken as 1/120.

It follows that, by making assumptions as to the thickness of air taking part in rain production and its moisture content and using the vertical velocities obtained from the above formula, the rate of rainfall at a front can be calculated. However, it is found that with an active front the calculated rainfall is only a comparatively small fraction of the actual rainfall. The discrepancy undoubtedly arises from the following considerations: (1) the frontal lifting is much less than the actual lifting due to the realization of convective instability in the warm air, and (2) the effect of the presence of ice crystals in the upper parts of the cloud falling through the water drops lower down could greatly increase the rainfall above the calculated value.

The vertical velocity in the warm air at 8,400 ft. on August 8, 1946 was, assuming a frontal slope of 1/120,

$$15/120 = \tfrac{1}{8} \text{ kt.} = 12\tfrac{1}{2} \text{ ft./min.}$$

and the vertical velocity at other heights would be inversely proportional to the density at the height considered. It would take the air about 6 hr. to be lifted vertically 5,000 ft. at approximately 13–14 ft./min. and the rate of rainfall would not exceed 2 mm./hr., which is a very low value.

It will be realised, therefore, that a quantitative estimate of the rainfall which will occur at a given place due to a given front can only be made from previous experience of similar situations in which such variables as frontal lift,

moisture content, humidity and instability have been correlated with actual rainfall. The hodograph will be used to decide when lifting is occurring and whether convective instability will be realised by the lifting; but cannot, unfortunately be used in calculating the rainfall directly.

Conclusion.—The foregoing examples should have been sufficient to give readers a good idea of the scope, use and value of the method of analysing upper wind structure near frontal surfaces by means of the hodograph. Many other interesting examples of the method could have been given had space permitted.

The hodograph can be used with advantage in other than frontal situations, but then no deductions as to vertical motion can be made.

Care should be taken when dealing with occlusions as the normal wind in the warm air above an occlusion does not exhibit anything like the marked increase with height shown by active warm fronts, but this does not mean that they will give no rain.

DETERMINATION OF THE TRUE MEAN VAPOUR PRESSURE OF THE ATMOSPHERE FROM TEMPERATURE AND HYGROMETRIC DATA

By E. J. SUMNER, B.A., and G. A. TUNNELL, B.Sc.

Part I

In practically any standard text-book of climatology the reader will find mean maps of barometric pressure, dry-bulb temperature, rainfall and so on; but maps of the mean moisture content of the atmosphere are rare, and really accurate maps, at least on a global scale, are non-existent. The Climatology Division of the Meteorological Office under the direction of Dr. C. E. P. Brooks, set out to remedy this deficiency. It was proposed to produce mean water-vapour-pressure maps, at screen height reduced to mean sea level, for the entire world for each season of the year, using all the climatic data available. The work is not yet complete, but it seemed opportune to give an account of how one particular difficulty was tackled. A fuller and more rigorous treatment is to be published elsewhere. Now vapour pressure is a non-linear function of the dry-bulb temperature and the relative humidity. Given the two latter values the corresponding vapour pressure may be computed from a formula or tables, but the mean vapour pressure cannot be determined from mean temperature and humidity using the same formula. A numerical example will illustrate the point: Helwan, Egypt, has a monthly mean temperature and relative humidity of 300·8°A. and 47 per cent. respectively, for July 1906–20. The vapour pressure computed from these values using standard tables[1]* is 17·5 mb., whereas the true mean (*i.e.* the mean of individual values) is 16·1 mb., 1·4 mb. less.

Most climatological stations throughout the world publish only averages of temperature and relative humidity, sometimes with the range of one or both. Others give wet- and dry-bulb temperatures, or dry-bulb and dew-point temperatures. The vapour pressure value derived from these published means is, as we have seen, liable to depart considerably from the true mean because

*These numbers refer to the list of references on p. 263.

of the " error of the means " as it may be called, and the following account deals with the various methods of determining the true mean vapour pressure. It is shown how the errors arise in each case and what their magnitude is likely to be in various climatic regions. Some indications as to how to compute these errors in certain cases quickly from existing data are also given, although on occasions the question is not so much one of speed, as of getting the required mean vapour pressure at all.

Calculation of mean vapour pressures from dry-bulb temperature and relative humidity data.—If T is the dry-bulb temperature, a the corresponding saturation vapour pressure (written $a(T)$ where its explicit dependence on temperature requires to be brought out), and b the relative humidity expressed as a decimal fraction, then e, the vapour pressure of the atmosphere, is equal to ab. The true mean vapour pressure, $\bar{e}$, for n observations, is given by

$$\begin{aligned} \bar{e} = \frac{1}{n}\Sigma e = \frac{1}{n}\Sigma\, ab &= \bar{a}\bar{b} \\ &= \bar{a}\bar{b} + \frac{1}{n}\Sigma\,(a-\bar{a})\;(b-\bar{b}) \\ &= \bar{a}\bar{b} + r\sigma_a\sigma_b, \qquad \ldots\ \ldots\ (1) \end{aligned}$$

where r is the coefficient of correlation between a and b, σ_a the standard deviation of the a's, and σ_b that of the b's.* Let the value of the vapour pressure determined directly from the mean temperature $\overline{T}$, and mean humidity, $\bar{b}$ be E, then $E = a(\overline{T})\bar{b}$, $a(T)$ being the value of the saturation vapour pressure corresponding to the mean temperature. The amount, S, to be added to this value in order to give the true mean is given by

$$S = \bar{e} - E = \left\{\bar{a}(T) - a(\overline{T})\right\}\bar{b} + r\sigma_a\sigma_b \qquad \ldots\ \ldots\ (2)$$

There are therefore two distinct sources of error: the first, S_1, owing to the non-linearity of the relation between temperature and saturation vapour pressure; and the second, S_2, owing to the correlation between saturation vapour pressure and relative humidity, which arises from the obvious fact that the equation $e = ab$ is non-linear in a and b. To calculate the correction S, $\bar{a}$, σ_a, and r must be expressed in terms of temperature and humidity data ($\bar{a}$ and σ_a are expressible in terms of temperature only). We shall deal with each item in turn.

If the units of temperature and vapour pressure are degrees absolute and millibars respectively, then

$$\log\left\{\frac{a(T)}{a(T_0)}\right\} = \alpha\left(\frac{1}{T_0} - \frac{1}{T}\right) \qquad \ldots\ \ldots\ (3)$$

where T_0 is some convenient " zero " temperature, and α is a constant differing for ice and water[2]. The theoretical values of α for saturation with respect to water or supercooled water and ice are 5,423 and 6,140 respectively. In practice, a value of α of 5,305 for water has been found to give better agreement with accepted values of $a(T)$. It was arrived at by assuming a relationship of the form $\log a(T) + \alpha/T = \beta$, as suggested by theory, and finding by least squares the most probable values of the constants α and β over the temperature range 260–310°A., using values of the saturation vapour pressure at one-degree intervals as given by the British hygrometric tables[1]

*A bar placed over a symbol denotes the mean value.

up to 304°A., and thereafter from the Smithsonian tables.[3] The exact result was $\log a(T) + 5304{\cdot}87/T = 21{\cdot}255$. This equation may be put in the form of equation (3), where $a(T_0)$ and T_0 now represent any point on the best-fitting curve, in which case $a(T_0)$ is not necessarily the actual value of the saturation vapour pressure at the temperature T_0. The difference is inappreciable, however, and equation (3), with $\alpha = 5{,}305$, has been found to be extremely accurate with any pair of initial values which actually occur, and we have adopted it in the subsequent analysis.

If T' is the departure of a particular temperature from the average of the n observations of which it forms part, *i.e.* $T = \overline{T} + T'$, we may expand $a(T)$ by Taylor's theorem in the form

$$a(T) = a(\overline{T}) + \frac{T'}{1!}\left(\frac{da}{d\overline{T}}\right)_{\overline{T}} + \frac{T'^2}{2!}\left(\frac{d^2a}{d\overline{T}^2}\right)_{\overline{T}} + R_3,$$

where R_3 is the remainder after three terms. There are n equations of this form corresponding to each temperature reading; summing and dividing by-n we get

$$\bar{a}(T) = \frac{1}{n}\Sigma\, a(T) = a(\overline{T}) + \left(\frac{d^2a}{d\overline{T}^2}\right)_{\overline{T}}\left(\frac{1}{2n}\,\Sigma\, T'^2\right) + \frac{1}{n}\,\Sigma R_3$$

since $\Sigma T' = 0$. Now from equation (3)

$$\frac{d^2a}{d\overline{T}^2} = \frac{a(\overline{T})}{\overline{T}^4}(\alpha^2 - 2\alpha T)$$

Therefore

$$\bar{a}(T) = a(\overline{T}) + \frac{a(\overline{T})\sigma_T^2}{\overline{T}^4}(\alpha^2 - 2\alpha T) + R,$$

in which R is the mean remainder and σ_T is the standard deviation of the temperature data. Although a rigorous proof cannot be given here, it can be shown that R is normally negligible by comparison with the other terms, and our final equation expressing $\bar{a}(T)$ in terms of the temperature data only is

$$\bar{a}(T) = a(\overline{T})\left\{1 + \frac{\sigma_T^2}{2\overline{T}^4}(\alpha^2 - 2\alpha T)\right\} \qquad \ldots\ldots (4)$$

The following is a typical example illustrating the accuracy of this equation. The monthly mean temperature of Basra for July 1938–41 is 306·89°A., and $\sigma_T = 3{\cdot}71$°C., $a(\overline{T}) = 52{\cdot}84$ mb. (from tables), and $\bar{a}(T) = 53{\cdot}84$ mb.* The actual difference between these two values is 1·01 mb. whereas $\bar{a}(T) - a(\overline{T})$ calculated from the above equation, is 1·00 mb. For temperatures which occur in nature $\bar{a}(T)$ is always greater than $a(\overline{T})$.

To determine σ_a we merely put $a = \bar{a} + a'$ and $T = \overline{T} + T'$ in (3), expand, take averages of both sides and neglect powers higher than the second. We shall leave the algebra to the reader; the result is

$$\frac{\sigma_a}{\bar{a}} = \frac{\alpha\sigma_T}{\overline{T}^2}$$

However, the equation finally adopted was

$$\frac{\sigma_a}{a(\overline{T})} = \frac{\alpha\sigma_T}{\overline{T}^2} \qquad \ldots\ldots (5)$$

It expresses σ_a in terms of the mean temperature and the standard deviation of the temperature only, and is rather more accurate than the first. It can be

*The standard deviation is calculated from the monthly mean temperatures at each of the 24 hours of the day, and $\bar{a}(T)$ is the mean of the saturation vapour pressures at these temperatures.

taken as applying to all diurnal ranges of temperature, and to all hourly and annual ranges less than 20°C., to well within 5 per cent. of the actual standard deviation of saturation vapour pressure.

Substituting from (4) and (5) in (2), we get

$$S = \left\{ \frac{a(\overline{T})\sigma_T^2}{2\overline{T}^4}\left(\alpha^2 - 2\alpha\overline{T}\right)\right\}\overline{b} + ra(\overline{T})\frac{\alpha\sigma_T\sigma_b}{\overline{T}^2} \quad \ldots\ldots (6)$$

This equation gives a remarkably accurate value for the required correction, and except for the correlation coefficient r, refers only to the original temperature and humidity data. Before proceeding further it would be as well to give some typical values of the entities which occur in it. Tables I, II and III represent a small selection of a large number of stations for which the calculations were made. It will be seen at a glance that the total error S is negligibly small for monthly means at a particular hour, and it can be taken for granted that if the mean temperature and mean relative humidity are used to compute the vapour pressure we shall generally be within 0·2 mb. of the true mean, especially in the tropics. Such corrections are not significant, and reference will be made to means of this type again in Part II.

The other types of means most frequently used will be discussed separately.

Monthly means.—The values of r, σ_a, σ_b in Table II were derived from the 24 monthly mean values of temperature and relative humidity at each of the 24 hours (or as many as were available down to a minimum of eight). The

TABLE I—MONTHLY MEANS AT SPECIFIED HOURS

Place	Date	Time	$\overline{T}$	$\overline{b}\times$ 100	r	σ_a	$\sigma_b\times$ 100	σ_T	S_1	S_2	S
		G.M.T.	°A.	%		mb.	%	°C.	*mb.*	*mb.*	*mb.*
Aboukir	Jan. 1946	0600	286·8	75	−0·74	2·1	11·8	2·1	0·10	−0·18	−0·08
		1200	290·0	60	0·00	0·9	5·7	0·7	0·01	0·00	+0·01
	July 1946	0600	299·0	75	−0·04	1·1	5·9	0·5	0·01	0·00	+0·01
		1200	300·9	67	−0·15	1·8	6·6	0·8	0·03	−0·02	+0·01
New York	Jan. 1941	0600*	270·3	71	+0·47	1·8	13·7	4·5	0·17	+0·11	+0·28
		1200*	273·2	65	−0·04	1·7	14·6	3·6	0·12	−0·01	+0·11
	July 1941	0600*	293·9	78	+0·05	3·9	10·0	2·5	0·22	+0·02	+0·24
		1200*	299·7	62	−0·47	8·2	17·9	3·9	0·50	0·70	+0·20
Kew	Jan. 1935	0600	277·6	87	0·00	2·1	9·6	3·4	0·19	0·00	+0·19
		1200	279·0	80	−0·07	2·0	9·7	3·1	0·14	−0·01	+0·13
	July 1935	0600	278·6	81	+0·09	2·0	7·3	1·8	0·11	+0·01	+0·12
		1200	294·7	54	−0·21	4·4	8·8	2·6	0·30	−0·08	+0·22

* 75° West Meridian Time

TABLE II—MONTHLY MEAN VALUES

Place	Month	Period	$\overline{T}$	$\overline{b}\times$ 100	r	σ_a	$\sigma_b\times$ 100	σ_T	S_1	S_2	S
			°A.	%		mb.	%	°C.	*mb.*	*mb.*	*mb.*
Helwan	Jan.	1906–20	286·0	58	−0·99	2·8	9·9	2·7	0·13	−0·25	−0·12
	July	1906–20	300·8	47	−0·98	10·1	19·4	4·5	0·54	−1·92	−1·38
Alexandria	Jan.	1906–20	287·7	69	−0·99	2·0	6·0	1·8	0·07	−0·12	−0·05
	July	1906–20	298·6	75	−0·97	4·2	5·8	2·1	0·18	−0·23	−0·05
Kew	Jan.	1935	278·2	84	−0·98	0·4	3·9	0·7	0·01	−0·02	−0·01
	July	1935	292·0	66	−0·99	4·1	12·5	2·9	0·22	−0·51	−0·29

correction S in this case is the departure of the vapour pressure, computed from the mean temperature and humidity, from the average of the hourly values computed in the same way from the monthly mean temperature and humidity at the hours, each of which is as already shown very close to the true value. Thus, adding S to the computed vapour pressure should give the true mean to within 0·2 or 0·3 mb. on an average.

It is obvious from the table that we are dealing with much bigger errors than have previously arisen, and it is possible to give a much more systematic account of them. The correlation coefficient r is now always negative and as near unity as to make no difference, and therefore our fundamental equation becomes

$$S = \left\{\frac{a(\overline{T})\sigma_T{}^2}{2\overline{T}^4}(\alpha^2 - 2\alpha\overline{T})\right\}\bar{b} - \left\{\frac{a(\overline{T})\alpha\sigma_T}{\overline{T}^2}\right\}\sigma_b \quad .. \quad (7)$$

The two terms which make up the correction are always of opposite sign in this case, which helps to diminish the error, but the negative one invariably overrides the other, except possibly when the value of S is very small indeed. In an unpublished paper we have also found a relationship between σ_T, σ_b, and $\bar{b}$, which simplifies the equation further. It is

$$\frac{\sigma_b}{\bar{b}} = \alpha_1 \frac{\sigma_T}{\overline{T}^2} \quad .. \quad (8)$$

where α_1 is a constant which is equal to α when there is no diurnal variation of vapour pressure at the place in question, and which is greater or less than α according to whether the vapour-pressure profile has a minimum during the day-time or not; the bigger the amplitude of the variation the bigger the effect. With the aid of this equation we have shown that S is roughly proportional to the square of the temperature range, the constant of proportionality increasing both with the mean temperature and the range of relative humidity. For mean diurnal temperature ranges less than 10°C., which include those of most temperate regions and all coastal stations with an on-shore wind, even in the tropics, the correction is usually much less than 0·5 mb.; but, above this range, it increases very rapidly, depending on the range of relative humidity. The greatest errors are experienced in arid regions in the tropics, well removed from the coast, where they may reach 2 mb. or more.

Annual means.—The various values of r, σ_a, σ_b, etc., in Table III were calculated from the twelve monthly mean temperatures and relative humidities. The quantity S is the departure of the mean vapour pressure, computed from the annual means of temperature and humidity, from the average of the computed monthly means, each of which is generally greater than the true monthly mean of vapour pressure. In temperate and polar regions, where the biggest annual ranges are experienced, this usually amounts to 0·3–0·4 mb. at the most, and the value of S gives a good idea of the magnitude of the error of

TABLE III—ANNUAL MEAN VALUES

Place	Period	$\overline{T}$	$b\times$ 100	r	σ_a	$\sigma_b\times$ 100	σ_T	S_1	S_2	S
		°A.	%		mb	%	°C.	*mb.*	*mb.*	*mb.*
Helwan	1906–20	294·2	50	−0·47	8·0	6·8	5·2	0·58	−0·25	+0·33
New York	1941	285·6	62	+0·07	8·9	3·9	9·1	1·38	+0·03	+1·41
Kew	1935	283·7	77	−0·73	4·5	6·3	4·9	0·46	−0·21	+0·25
Blagovyeshchensk	7 yr.	273·3	77	+0·13	8·8	5·9	15·9	2·94	+0·07	+3·01

the means. For annual means at a particular hour the order of magnitude of the error is about the same as that given in the table, and S represents the true correction more accurately.

The correlation coefficient r is here very variable, and no general rules can be given about it. The correction always seems to be positive, partly because the correlation is smaller than with monthly means, but mainly because the annual ranges of temperature are, in proportion, larger than those for humidity. Generally speaking the amount of moisture in the air depends on its capacity to receive it, and a seasonal rise of temperature is invariably associated with a rise of moisture content and a correspondingly small range of relative humidity.

Mean vapour pressures may be in error by over 3 mb. in high latitudes if computed from annual means of temperature and humidity, but are usually more or less correct in the tropics. This computed value is always less than the true mean vapour pressure and is very approximately proportional to the square of the temperature range. It is usually best to work out the monthly means with their appropriate corrections and average them to get the annual mean.

(To be continued)

REFERENCES

1. London, Meteorological Office. Hygrometric tables 4th edn, London, 1940.
2. SHAW, SIR NAPIER; Manual of meteorology. Vol. III. The physical processes of weather. Cambridge, 1930, p. 239.
3. Washington, Smithsonian Institute. Smithsonian meteorological tables. *Smithson. misc. Coll., Washington, D.C.*, **86**, 5th revised edn, 1931.

SOME CORRELATIONS CONCERNING THE THICKNESS OF THE 500–300-MB. LAYER

BY R. MURRAY, M.A.

Introduction.—Correlation coefficients and regression equations connecting the thickness of the 500–300-mb. layer with (1) temperature on the 500-mb. surface, (2) thickness of the layer 700–500 mb., and (3) temperature on the 300-mb. surface are given in this note. In addition some remarks are made regarding the occurrence of the tropopause below 300 mb.

A good deal of the substance of this note is already empirical knowledge to upper air analysts, but it is desirable that it should be put on paper in as definite a form as possible.

The data used consisted of 943 temperature soundings at Larkhill and Lerwick for the months of January, April, July and October 1947. A great variety of weather was represented by these soundings. The conclusions reached from the analysis may therefore be considered applicable to the British Isles generally, and probably, in only slightly modified form, to much of the eastern Atlantic and Europe between latitudes 45°N. and 65°N.

Correlation of the thickness of the 500–300-mb. layer with temperature at 500 mb.—S. Petterssen* found a correlation coefficient of about ·97 between the 500–400-mb. thickness and the temperature on the 500-mb.

*PETTERSSEN, S.; Relation between the temperature in the 500-mb. surface and the thickness of the layer from 500 to 400 mb. *S.D.T.M. met. Off., London*, No. 88, 1944.

surface. In our case practically the same correlation results—actually, $\cdot 968 \pm \cdot 001$.

The regression equation giving the most probable value of t_3 when T_5 is known is:—

$$t_3 = 23{\cdot}47\ T_5 + 1{,}884$$

where t_3 = thickness of the 500–300-mb. layer in feet, and T_5 = temperature at 500 mb. in degrees Fahrenheit.

The standard error of t_3 for given T_5 is 66 ft. In other words the value of t_3 obtained from the regression equation will be different from the true value of t_3 by less than about 130 ft. on rather more than 95 per cent. of occasions. Table I is derived from the regression equation.

TABLE I—500–300-MB. THICKNESS CORRESPONDING TO TEMPERATURE AT 500 MB.

T_5 (°F.)	−35	−30	−25	−20	−15	−10	−5	0	5	10	15	20
t_3 (ft.)	11,063	11,180	11,297	11,415	11,532	11,649	11,766	11,884	12,001	12,119	12,236	12,353

Correlation of the thickness of the 500–300-mb. layer with the thickness of the 700-500-mb. layer.—The correlation coefficient between t_3 and t_5 is equal to $\cdot 944 \pm \cdot 002$ (t_5 = thickness of 700–500-mb. layer in feet), and the required regression equation is:—

$$t_3 = 1{\cdot}306\ t_5 + 751$$

Here the standard error of t_3 for given t_5 is 87 ft. and Table II is derived from the regression equation.

TABLE II—500–300-MB. THICKNESS CORRESPONDING TO 700–500-MB. THICKNESS

t_5 (ft.)	8,000	8,100	8,200	8,300	8,400	8,500	8,600	8,700	8,800	8,900
t_3 (ft.)	11,199	11,330	11,460	11,590	11,721	11,852	11,983	12,113	12,244	12,374

General remarks.—It appears that slightly better estimates of t_3 can be made by using T_5 than by using t_5. However, in practical upper air work it will often be more convenient to make estimates based on knowing t_5. A total correlation coefficient and regression equation connecting t_3 with T_5 and t_5 could be worked out, but the resulting probable values of t_3 could be only slightly more accurate than estimates made from T_5 alone.

Correlation of the thickness of the 500–300-mb. layer with temperature at 300 mb.—As the tropopause is occasionally located at a lower level than the 300-mb. surface, it was thought desirable to work out correlation coefficients and regression equations in the following three cases:—

(*a*) *All occasions* (*i.e. position of tropopause not specified*).—Let T_3 be the temperature at 300 mb. in degrees Fahrenheit. Then correlation between t_3 and T_3 is $\cdot 867 \pm \cdot 005$.

The regression equation giving the most probable value of T_3 when t_3 is known is:—

$$T_3 = \cdot 0268\ t_3 - 365$$

The standard error of T_3 for given t_3 is 4·2°F.

(*b*) *Tropopause at or above* 300 *mb.*—There were 866 occasions. The correlation coefficient is $\cdot 911 \pm \cdot 004$ and the regression equation is:—

$$T_3 = \cdot 02915\ t_3 - 393$$

The standard error of T_3 for given t_3 is 3·5°F.

J. M. Craddock* found a correlation coefficient of ·96 between the temperature at 500 mb. and the 700–500-mb. thickness. At first sight it may be rather surprising that in our case the correlation coefficient between t_3 and T_3 is only ·911 and not about ·95 in the upper troposphere. There is little doubt that the correlation coefficient would be somewhat greater than ·911 if those cases, in which the temperature lapse rate near 300 mb. changed appreciably yet without quite qualifying to be classed as a tropopause, had been excluded from the statistics.

(*c*) *Case of tropopause below* 300 *mb.*—There were 77 occasions. The correlation coefficient is ·70 ± ·04, and the regression equation is:—

$$T_3 = \cdot 02715\, t_3 - 362$$

The standard error of T_3 for given t_3 is 4·8°F.

Table III gives the probable values of T_3 for certain values of t_3 for all three cases. In case (*c*) it applies fairly well within the range 11,200 $t \leqslant_3 \leqslant$ 11,700.

TABLE III—TEMPERATURE AT 300 MB. CORRESPONDING TO 500–300-MB. THICKNESS

500–300-mb. thickness	Temperature at 300 mb. (*a*) All occasions	(*b*) Tropopause at or above 300 mb.	(*c*) Tropopause below 300 mb.
ft.		*degrees Fahrenheit*	
12,400	−33	−32	—
12,300	−35	−34	—
12,200	−38	−37	—
12,100	−41	−40	—
12,000	−43	−43	—
11,900	−46	−46	—
11,800	−49	−49	—
11,700	−51	−52	−44
11,600	−54	−55	−47
11,500	−57	−58	−50
11,400	−59	−61	−52
11,300	−62	−64	−55
11,200	−65	−67	−58

General remarks.—The regression equations and Table III should prove helpful in forecasting temperatures at 300 mb. when forecasts are made of the 500–300-mb. thickness (as is the present British practice). If the position of the tropopause is likely to be very doubtful, the regression equation or column (*a*) in Table III will give a first approximation to the temperature at 300 mb. If the tropopause is expected to be above 300 mb., the information in column (*b*) should be used, and if the tropopause is probably below the 300-mb. level, use should be made of the results in column (*c*). In each case synoptic experience will modify the forecast based on the statistical method.

Occurrence of the tropopause below 300 mb.—About 8 per cent. of all the soundings showed the tropopause below the 300-mb. level. When t_5 was equal to, or greater than, 8,500 ft., the tropopause was invariably higher than the 300-mb. level. Table IV gives the percentage frequency of occurrence of the tropopause below 300 mb. for various values of t_5.

*CRADDOCK, J. M.; Estimation of temperature in the 700-mb. and 500-mb. surfaces. *Met. Mag., London*, **78**, 1949, p. 36.

TABLE IV—FREQUENCY OF TROPOPAUSE BELOW 300 MB. FOR VARIOUS VALUES OF 700–500-MB. THICKNESS

t_5 (ft.)	8,500	8,450	8,400	8,350	8,300	8,250	8,200	8,150	8,100	8,050	8,000–7,800
Frequency (%)	0	3	11	18	3	7	19	20	33	32	35

It will be seen that, on the whole, the smaller the value of t_5 (the colder the air) the greater the chance of the tropopause being below 300 mb. However, the most useful working rule which comes out from the statistics is that it is nearly a certainty that the tropopause will be at a greater height than the 300-mb. surface in cases when t_5 is greater than 8,450 ft. (8,400 ft. is a standard thickness line on the 500-mb. chart).

METEOROLOGICAL RESEARCH COMMITTEE

The seventh meeting of the Physical Sub-Committee was held on July 20, 1949.

Members heard with interest that observations of temperature and wind to a height of about 100,000 ft. had recently been made on five occasions, using special balloons to carry the radio-sonde.

The Sub-Committee discussed a paper[1] describing recent experiments at Kew Observatory on heat transfer near the ground by N. E. Rider and Dr. G. D. Robinson.

A report[2] from Mr. R. F. Jones on the relation between the radar echoes from cumulus and cumulonimbus clouds and the turbulence within these clouds was received with interest.

Papers on condensation processes in clear air at low temperatures and self propagation of ice crystals in supercooled water clouds were considered and future work on low temperature investigations decided.

Other papers considered were on the size distribution of raindrops[3] and the detection of icing conditions by radar[4], both by Mr. R. F. Jones; condensation trails made by jet aircraft were also discussed.

[1] *Met. Res. Pap., London*, No. 491
[2] *Met. Res. Pap., London*, No. 484
[3] *Met. Res. Pap., London*, No. 453
[4] *Met. Res. Pap., London*, No. 482

ROYAL METEOROLOGICAL SOCIETY

At a meeting of the Royal Meteorological Society on Wednesday, June 15, 1949, Sir Robert Watson-Watt, President, in the Chair, the following papers were read:—

*Hewson, E. W.—The dissipation of scattered and broken cloud.**

In the absence of the Canadian author this paper was read by Prof. Brunt, who said that the paper had had its origin in a lecture he had given in 1936.

It had been shown in 1944 that the rate of net loss of heat by a cloud due to radiation was $\gamma\sigma\,(T_T^4 - T_S^4 + T_B^4)$ where $\gamma = 0{\cdot}35$, σ = Stefan's constant, and T_T, T_B and T_S were the absolute temperatures at the top and base of the cloud and surface of the earth, respectively. With this value (or more accurately using Elsasser's radiation chart) it was possible to deduce the behaviour of the cloud under radiation conditions from the tephigram. As the cloud cooled, its

* *Quart. J. R. met. Soc., London*, **74**, 1948, p. 243.

temperature followed an isobaric curve on the tephigram, and then, being colder than its environment, a saturated adiabatic until it was at the same temperature as its environment. In this way a cooling cloud would descend and, in fact, become warmer and progressively drier as it descended. The process, as illustrated in slides and on the blackboard, was in steps but these could be as small as desired and, in the limit, the cooling would take place along the environment curve.

The total amount of the different states of water in the cloud could be represented by a single value of the symbol ξ where $\xi = x+y+z$, x, y and z being the numbers of grams of water vapour, liquid water and ice, respectively, per kilogram of dry air; and this could be represented on the tephigram for all pressures, by the saturated mixing-ratio line of the same value.

When the cloud had " cooled " sufficiently so that its temperature reached this ξ line, any further cooling would result in evaporation and the cloud would dissipate.

Several slides were shown illustrating the process for various different lapse rates of the encironment curve and how it was theoretically possible for the cloud to descend even as far as the ground. The radiation did take time, however, and a period of 6 hr. was quite normal.

Speaking for himself, Prof. Brunt doubted whether radiation was the only effect ; not only did the cloud descend, but, in descending, the air beneath the cloud would probably also descend, and since this air would warm at the dry adiabatic lapse rate a temperature difference would arise sufficient to set up convection. Once, at Nottingham, he had been able to describe a sheet of cloud as 8 tenths and as dissipating within half an hour. He had seen rolls and breaks near the edge of the sheet and had suspected turbulence; the amount of cloud had fallen to 3 tenths within 15 min.

The technique of the ξ line was useful in giving a criterion of the descent required before a cloud dissipates; but it was necessary to remember that a cloud can fall through the air.

Mr. A. W. Brewer had had to forecast in north-east England during the war and try to determine what would happen to a given sheet of cloud. He drew diagrams of the history of 10 tenths sheets of thin cloud which either descended and became thicker or dissipated, even though, initially, the environments were similar. The final result seemed to depend on the amount of turbulence present.

Mr. D. J. Schove had observed warm-sector stratus break into rolls and disappear.

Dr. R. C. Sutcliffe wondered if the step-by-step process could be written as a differential equation which would perhaps be better understood. It was important to realise that instability for cloud-laden air was the same for both up and down motion. In conclusion, he thought the paper was a useful exercise in what could be done with the tephigram, and would be valuable for students.

Prof. Brunt, in reply, mentioned that he had not had the opportunity of studying the temperature structure in north-east England before. In his experience of lecturing he had found that his " simple-minded " students preferred step-by-step methods to differential equations.

*Crocker, A. M.—Synoptic applications of the frontal contour chart.**

In the absence of the author, also Canadian, this paper was read by Dr. J. S. Farquharson. A frontal-contour chart is prepared in two steps:—

(*a*) by analysing all available upper air data and finding levels of separation of the air masses present, and

(*b*) by drawing the lines of intersection of the frontal surfaces with the pressure surfaces of 900, 800, 700 . . . mb.

From these frontal-contour charts it was frequently possible to identify a cold air mass penetrating southwards in a long tongue; warmer air, moving in further north and progressively lower, might cut off the cold air completely leaving a cold dome behind. Mr. Crocker preferred the term " cold dome " to Mr. Douglas's term " cold pool "† because his frontal-contour charts indicated that they were dome-shaped, unless they reached the tropopause when they were similar to the frustrum of a cone.

The paper was illustrated by a detailed analysis of a cold dome covering south-west United States including tephigrams, frontal-contour charts and isobaric-contour charts as well as the normal surface charts. The charts showed how the cold dome moving north-eastwards, as shown by a low on the 300-mb. charts, united with a surface low which was then moving north-westwards; the surface low deepened more rapidly when the uniting took place and both lows then moved almost together.

Among the advantages of frontal-contour charts was the ability to estimate from them probable vertical movements and condensation.

Dr. Farquharson, in opening the discussion, thought that there was no more justification for the term " cold dome " than for " cold pool ". " Cold pool " had been invented during telephone conferences in Bomber Command; the name had stuck and he was in favour of it for day-to-day purposes.

Mr. A. G. Matthewman had been investigating frontal structure. There were difficulties in the Norwegian concept of a front; some people preferred other definitions, *e.g.* a line of appropriate weather. Fronts might be rather vague in regions of frontolysis and frontogenesis. He had been experimenting with constant-pressure charts with isopleths of wet-bulb potential temperature which he thought took frontal-contour charts in their stride. He was doubtful of Mr. Crockers' statement that the air round the surface centre was quasi-homogeneous, and he produced charts he had constructed to substantiate his belief that the deepening had been caused by a limited occlusion process, in the non-homogeneous polar maritime air.

Mr. H. H. Lamb had worked with both frontal-contour charts and thickness charts; and thickness charts were important in the appreciation of thermal steering. He thought that there were both cold pools and cold domes; domes were sometimes present in cold pools, but cold pools, which were defined as closed areas on the thickness chart, sometimes included patches within a single air mass. He described an interesting situation in March 1946 when there was both a cold dome and a cold pool.

Quart. J. R. met. Soc., London*, **75, 1949, p. 57.
†DOUGLAS, C. K. M.; Cold pools. *Met. Mag., London*, **76**, 1947, p. 225.

[To face page 268

CUMULUS AND CUMOLONIMBUS IN THE RAINY SEASON ON THE COAST OF BRITISH EAST AFRICA
(see p. 270)

CUMULUS AND ALTOCUMULUS OVER CENTRAL TANGANYIKA

Dr. R. C. Sutcliffe saw no grounds for controversy in nomenclature; either term was appropriate according to circumstances. The cold " whatever it is " had received a lot of attention; it existed over continents in winter, associated with anticyclones, but persistent cold pools were more typical of cold depressions.

In reply, Dr. Farquharson said that frontal-contour charts were useful for special investigations, but not as a general tool of forecasting owing to the lack of sufficiently detailed information for their construction.

ROYAL ASTRONOMICAL SOCIETY

At a geophysical discussion of the Royal Astronomical Society on May 27, 1949, the following paper by Mr. C. S. Durst was read:—

On surface friction and turbulence in the ocean.

The purpose of the paper was to show how the roughness of the ocean surface due to wave formation affected the coefficient of surface friction and how this varied with wind speed. This variation also enabled a calculation to be made of the coefficient of turbulence in the ocean when it was under the influence of winds of varying strengths.

It is usually assumed that the surface resistance, Fx, is proportional to the density and the square of the wind speed, the equation being written:—

$$F_x = K\rho V_s^2 \qquad .. \qquad (1)$$

where ρ is density and V_s the " surface " wind. The value of K is often assumed to be 0·002 but Sutcliffe* found that over the ocean the value was much lower. Sutcliffe, in making this estimate, used the formula:—

$$F_x = \int_0^h 2\ \omega \sin \phi\ \rho\ (v - v_0)\ dz \qquad .. \qquad (2)$$

where v is the wind component at right angles to the " surface " wind direction, v_0 is the component of the geostrophic wind in the direction which is reached at height h, ω is the angular velocity of the earth and ϕ is latitude.

In the present paper this formula was used to estimate the surface resistance from two series of data, the first being pilot-balloon ascents made by D. A. Davies from S.S. *Manchester Port* and the second being observations made on H.M. Ships.

The conclusion reached from the examination was that the surface resistance over the sea varied as a higher power than the square of the "surface" wind, and it seemed that K in equation (1) was proportional to the surface wind speed.

To relate this result to the turbulence in the ocean a result deduced by Jeffreys† was invoked, namely:—

$$k = \frac{F_x}{2\ \omega \sin \phi\ j^2} \qquad .. \qquad (3)$$

where k is the coefficient of turbulence in the ocean (assumed constant with depth) and j is the velocity of the ocean current. The link between this formula and (1) was provided by an empirical result obtained by Durst‡ that the speed of the ocean current was proportional to the surface wind.

*SUTCLIFFE, R. C.; Surface resistance in atmospheric flow. *Quart. J. R. met. Soc., London*, **62**, 1936, p. 3.

†JEFFREYS, H.; On turbulence in the ocean. *Phil. Mag., London*, **39**, 1920, p. 578.

‡DURST, C. S.; The relationship between current and wind. *Quart. J. R. met. Soc., London*, **50**, 1924. p. 113.

Using this formula it was found that the coefficient of turbulence in the ocean was of the order of 10^{-2} for a light air, 30 for a moderate breeze of 15 kt. and 200 for a strong breeze of 25 kt.

In the discussion which followed, Prof. D. Brunt pointed out that the coefficient of skin friction depended on the height at which the " surface " wind was measured, and that with the sea observations this height had not been stated. To this Mr. Durst replied that the height of the " surface " wind observed at sea might be rather indefinite, but in the data used for the comparison of wind and current and for the determination of surface friction by pilot balloons the observations referred essentially to the same heights.

Prof. P. A. Sheppard asked if Mr. Durst had been able to find evidence of the change in the value of the drag coefficient at critical wind speeds as would be expected from the work of Munk. Mr. Durst replied that he had not—indeed the observations would be too few for such refinement. He felt that it would be well to endeavour to obtain more, and more accurate, observations perhaps from the Admiralty to settle the question if possible.

Dr. G. E. R. Deacon referred to Prof. Jeffrey's work on waves, and said that the explanation of the discrepancy between the magnitudes of the coefficient of turbulence deduced from the movement of ocean drift currents and that required in the formation of waves might be that the turbulence needed to create water movements was of a different type to that involved in the wave motion.

Mr. A. F. Crossley stated he had used Mr. Durst's data to calculate the value of the index on the assumption of a power law variation of wind with height. He exhibited a diagram which showed that the *Manchester Port* data (excepting light winds) fitted a power law. If, however, the coefficient of surface friction were calculated on the supposition that the power law variation held down to the surface it was found that the coefficient was nearer to that used by Prof. Taylor over the land than that deduced by Dr. Sutcliffe and now by Mr. Durst over the sea.

Mr. E. Gold surmised that when breaking waves occurred there would be a dissipation of energy and that the character of the turbulence might be quite different; indeed that new type of turbulence ought to be excluded from Mr. Durst's calculations.

NOTES AND NEWS

Clouds in Tanganyika

The cloud photographs facing pp. 253, 268 and 269 were taken by the late M. C. Gillman, who was Chief Engineer of the Tanganyika Railways.

The photograph facing p. 268 was taken at the end of April in the Dar-es-Salaam area and shows the typical heavy cumulus and cumulonimbus masses which form late in the day along the coast during the " rainy season " which marks the transition between the SE. and NE. monsoons of east Africa. As can be seen, the convection cloud is often associated with dense cirrus masses which are often the remains of the previous day's activity. Late in the night the convection cloud stratifies mainly in the medium and upper cloud levels so that the next morning is cloudy, sometimes in association with local

slight rain or drizzle. This, in fact, was the weather sequence on the morning that this photograph was taken. The surface wind throughout the day was mainly calm.

The photograph facing p. 269 was taken west of Dodoma, in central Tanganyika, during mid afternoon in December. These convection clouds, which further to the east were definitely fair-weather cumulus, have formed in the easterly airstream after forced ascent over the Saranda Scarp and thus have greater vertical development. Local very light showers may fall from these clouds during the late afternoon, but they quickly disperse towards dusk, and, even during the period of maximum heating the clouds are constantly dissolving and reforming. The general height of the plateau over the scarp is about 4,500 ft. and the clouds thus have a base which is usually about 8,000 ft. above sea level.

The description of the photograph facing p. 253 is given beneath it.

REVIEW

Wetter und Krankheiten. By Hellmut Berg. 8vo, 8 in. × 5¾ in., pp. iv + 140, *Illus.*, H. Bouvier u. Co., Bonn. 1948. *DM* 6.50.

This book on weather and disease discusses nothing so obvious as the connexion between lumbago and draughts, or between sunstroke and sunshine. Its nearest approach to familiar things is found in a single paragraph on the common cold, pp. 75-7, dealing with the work of E. Flach, published in 1938.

One of Flach's diagrams shows a well marked decrease in the incidence of colds with increasing wind speeds, as if the wind helps to blow the germs away. Relative humidity appears to make little difference, but the plot of incidence against diurnal temperature range shows a striking minimum of colds when the range is less than 2°C. From this one might deduce that good health is favoured by persistent cloudiness. Curiously enough, no evidence is produced for, or against, the popular belief that low temperatures are the cause of colds—a belief long ago disproved by polar explorers but still, apparently, held by the man in the street, who refuses to keep off the street because nobody can persuade him he has got an infectious disease.

However, it is rarely that any connexion can be established between disease and isolated meteorological elements like temperature, humidity and so on. Most of the book discusses the influence of more generalised phenomena such as fronts, inversions, terrestial magnetism and solar flares. These are brought into the investigation by use of the so-called " *n*-method " of taking the day of occurrence of a front, or what not, and seeing how the cases of illness are distributed about this day.

The results, set out in the chapter on " meteorotropic illnesses " the longest in the book, produce a bewildering miscellany which it would seem impossible at first to reduce to any sort of order. Infantile paralysis, for instance, is correlated with cold fronts in New York but not in Hesse, and rheumatism with subsidence before warm fronts or after cold fronts according to Flach, but with the actual passage of fronts according to Feige and Freund. Lung embolisms, say von Raettig and Nehls, happen on days of warm and cold fronts twice as often as they would if randomly distributed ; but two other workers, investigating fatal cases, find that fronts have the opposite effect in

summer and no influence in winter, and that fatalities from lung embolism show some correlation with disturbances of terrestial magnetism ; yet another worker finds that fronts have no demonstrable influence either way.

And so on, for more than twenty different diseases. One feels that any agreement between the various authorities, where it occurs, is as likely to be due to chance as to any real basis for their findings.

Fortunately the author, in a later chapter, sorts it all out for us on pages 93 and 98. Strong evidence is only apparent in the following cases :—

Death from all causes is strongly correlated with fronts of all kinds ; warm fronts are correlated with suicide and cold fronts with apoplexy, infantile paralysis and post-operative lung complications. Apoplectic stroke is least likely when barometric pressure is high. Influenza and rheumatism become more likely in the presence of inversions. Magnetic disturbances are correlated with tubercular haemorrhage from the lungs, and with eclampsia ; they are also liable to precede embolism by 4 or 5 days.

It seems questionable whether any of this great mass of statistical research can yet be put to any practical use, because the correlations are far from absolute. For instance, potential suicides at mental hospitals have to be watched all the time, and not merely when cirrostratus appears in the sky and AIRMET says there is a warm front coming. Berg gives particular attention to eclampsia, a disease characterised by convulsions at about the end of pregnancy. It can often be averted by taking strong measures as soon as premonitory symptoms appear. But what would an anxious husband say if the doctor, instead of getting on with his job, sat down beside the telephone and tried to contact the nearest magnetic observatory?

One wonders why some of the attempts at correlation, mentioned in the book, were ever undertaken. In each case the investigator must have made some wild guess as to how the phenomenon investigated could affect the disease, yet nowhere are we told what this guess was. However, once a relation is established hypotheses are put forward to account for it, and we are given several of these in the last two chapters. W. F. Peterson, who published a voluminous work " The Patient and the Weather " in America, is quoted as suggesting that fronts bring about their effects through alternate contraction and dilation of the vessels, presumably the blood vessels, in response to polar and tropical air respectively. Briefly, contraction reduces the oxygen supply to the tissues and impairs their resistance to disease; pathogenic substances are thus created which easily circulate through the body when the vessels expand once more and their walls become more penetrable. We are not told of any biochemical evidence for their theory. Nor is any reason given why south-westerly winds of continental origin should stimulate cell growth in cancer, as Peterson believes they do. Several other hypotheses of various kinds are equally tentative.

Some experiments of E. Findeisen on the effects of weather on colloids are quoted as being significant, owing to the prevalence of the colloid state in living substance. The electrical resistance of a colloid solution of arsenious sulphide becomes gradually reduced with time, and Findeisen found that this reduction is hindered by showers and thunderstorms and accelerated by cold fronts and föhn winds.

"Föhn sickness," characterized mainly by lassitude and other psychological symptoms, receives much attention from the author ; but any attempts to explain it must show why it suddenly ceases as the descending warm, dry air breaks through to ground level, and why sufferers cannot escape the symptoms even by staying indoors. Short-period fluctuations of atmospheric pressure, due to waves at the inversion, seem the most plausible explanation put forward so far. But lift attendants, bus drivers in hilly country, and sailplane pilots repeatedly climbing in thermals, subject themselves to pressure fluctuations of comparable period and amplitude without becoming föhn-sick.

One wonders whether the main influence of weather changes on the body is not brought about through the psychological factor, which is undoubtedly present in most diseases and especially in some of those discussed, such as gastric ulcer and asthma. Far greater changes of environment than some of those investigated, as Berg points out, can be experienced by merely going into or out of a room. If, as is generally accepted, the healthiest lives are those lived in the open air, then too much weather is better than too little. But nobody would think so from reading this book.

A. E. SLATER

OBITUARY

Mr. W. J. R. Pook, D.C.M.—We regret to announce the death of Mr. Pook which occurred at Barnes on July 24, 1949, after a long illness.

Mr. Pook entered the Meteorological Office in 1919 as a Clerk Assistant and at the time of his retirement in March 1949 had risen to the rank of Senior Experimental Officer. He served two tours of duty in the Middle East as a civilian, partly on administrative and partly on forecasting work. Mr. Pook saw service in France, Belgium and Italy with the Royal Artillery during World War I and was awarded the D.C.M. for conspicuous gallantry in the field. He formed part of the first meteorological contingent in France in World War II and for his services there was mentioned in despatches.

"Bill" Pook earned the highest regard of all members of the staff with whom he worked. His unfailing cheerfulness and the high standard he set himself were generally admired. His many unpublicised kindnesses to junior staff will long be remembered by many still remaining in the Office.

H. A. SCOTNEY

WEATHER OF JULY 1949

Mean pressure was between 1020 and 1025 mb. over a large area which included the Azores, Madeira and the southern parts of England and Ireland, and below 1010 mb. in the north-east of Canada. It was about 1015 mb. over most of Europe and North America. Deviations from the normal were small over Europe and North America, being generally positive over Europe and over the North Atlantic as far west as longitude 30°W., the excess being 5 or 6 mb. to northward and westward of the British Isles and in Scotland and Ireland.

Over the British Isles weather was mainly fine and warm with a thundery spell from the 13th to 17th, which affected most areas except north Scotland and broke the long period of dry conditions. Sunshine was generally above average, except in Ireland, most notably in south and south-west England.

Rainfall was well below average generally, but owing to intense falls during the thundery rains the normal was exceeded at a few irregularly distributed stations.

An anticyclone moved from the south-west of Ireland to the southern North Sea during the first three days and very fine warm weather prevailed. A trough of low pressure moving eastwards on the 4th brought small amounts of rain to most areas, and was followed by a cool northerly air stream. Maximum temperatures fell to the lower sixties and even, by the 7th, to 58° F. at Kew and Lympne, 57°F. at Felixstowe and Gorleston, and 55°F. at West Raynham. With anticyclonic conditions on the 8th and 9th, day temperatures rose again, subsequently reaching the higher eighties in many places, with a maximum of 90°F. on the 12th at several stations including Bristol and Camden Square. Meanwhile a depression situated over Spain on the 10th had deepened and moved north-westwards, turning north-east on the 13th and later east, to travel from the Scillies to the southern North Sea, from the 15th to the 18th. A secondary developed over the English Channel on the 13th and moved to the Irish Sea before filling up on the 14th, while associated troughs moved northwards over England and Wales from the 13th to 17th. During this period, with lower day temperatures, thundery conditions spread over most of the country. Rainfall distribution was irregular and sometimes very local; among the heavier falls were: 13th, 1·38 in. (out of a total of 1·72 in.) in 35 minutes at Elmdon and 2·40 in. in just over an hour at Holford, Somerset; 15th, 4·12 in. at March (Cambs.) and 3·39 in. at Afon Rheidol (Glam.); 16th, 2·77 in. at Chipping Norton and 2·60 in. at Crediton (Devon). Severe thunderstorms in the London area on the 16th caused damage and several deaths. A cooler north-westerly air stream established itself over the country on the 18th to 19th and drier conditions prevailed until nearly the end of the month. The troughs of a depression which passed to the north of Scotland gave some rain, mainly light, in the west and north on the 20th and 21st; but thereafter an irregular ridge of fairly high pressure, intersected only by weak troughs, maintained warm and fair weather, with very light winds, until the 26th; maximum temperatures again reached the eighties in many places and there were local thunderstorms in north-east England on the 25th. A feeble westerly current on the 26th was followed by more definite westerly conditions which persisted for the rest of the month. Slight rain or drizzle fell in many areas on the 27th, and subsequently there were frequent slight falls in the north and west, but the fine weather continued in the south until the 31st, when a depression moved north-east to the north of Scotland and the associated troughs travelled eastwards across the British Isles with light rain in all districts.

The general character of the weather is shown by the following provisional figures:—

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average	Percentage of possible duration
England and Wales	92	36	+2.6	68	−5	121	46
Scotland	82	32	+1.5	65	−5	105	30
Northern Ireland..	83	41	+1.3	77	−3	88	26

RAINFALL OF JULY 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ..	·84	35	*Glam.*	Cardiff, Penylan ..	1·31	43
Kent	Folkestone, Cherry Gdn.	·99	47	*Pemb.*	St. Ann's Head ..	2·00	77
,,	Edenbridge, Falconhurst	·39	17	*Card.*	Aberystwyth	1·99	65
Sussex	Compton, Compton Ho.	·31	11	*Radnor*	Tyrmynydd	1·09	27
,,	Worthing, Beach Ho.Pk.	·18	9	*Mont.*	Lake Vyrnwy	2·13	58
Hants	Ventnor, Roy. Nat. Hos.	·24	12	*Mer.*	Blaenau Festiniog ..	4·88	57
,,	Bournemouth	·38	18	*Carn.*	Llandudno	1·21	54
,,	Sherborne St. John ..	1·96	88	*Angl.*	Llanerchymedd ..	1·99	70
Herts.	Royston, Therfield Rec.	2·22	88	*I. Man.*	Douglas, Borough Cem.	4·49	147
Bucks.	Slough, Upton	·71	37	*Wigtown*	Port William, Monreith	2·68	95
Oxford	Oxford, Radcliffe ..	·91	38	*Dumf.*	Dumfries, Crichton R.I.	3·17	97
N'hant.	Wellingboro', Swanspool	1·49	65	,,	Eskdalemuir Obsy. ..	2·64	64
Essex	Shoeburyness	·20	11	*Roxb.*	Kelso, Floors	2·39	91
Suffolk	Campsea Ashe, High Ho.	1·25	54	*Peebles*	Stobo Castle	2·08	72
,,	Lowestoft Sec. School ..	·48	21	*Berwick*	Marchmont House ..	2·37	78
,,	Bury St. Ed., Westley H.	·89	36	*E. Loth.*	North Berwick Res. ..	1·91	74
Norfolk	Sandringham Ho. Gdns.	2·25	88	*Midl'n.*	Edinburgh, Blackf'd. H.	2·71	96
Wilts.	Bishops Cannings ..	1·43	57	*Lanark*	Hamilton W. W., T'nhill	1·58	55
Dorset	Creech Grange.. ..	·67	27	*Ayr*	Colmonell, Knockdolian	1·21	38
,,	Beaminster, East St. ..	1·57	60	,,	Glen Afton, Ayr San ..	2·07	49
Devon	Teignmouth, Den Gdns.	1·38	59	*Bute*	Rothesay, Ardencraig	2·60	66
,,	Cullompton	2·12	79	*Argyll*	L. Sunart, Glenborrodale	3·15	68
,,	Barnstaple, N. Dev. Ath.	1·75	65	,,	Poltalloch	2·02	49
,,	Okehampton, Uplands	2·13	66	,,	Inveraray Castle ..	3·63	73
Cornwall	Bude School House ..	1·83	75	,,	Islay, Eallabus ..	·85	25
,,	Penzance, Morrab Gdns.	1·51	56	,,	Tiree	1·44	40
,,	St. Austell, Trevarna ..	2·60	78	*Kinross*	Loch Leven Sluice ..	2·36	82
,,	Scilly, Tresco Abbey ..	1·18	53	*Fife*	Leuchars Airfield ..	3·02	116
Glos.	Cirencester	1·50	58	*Perth*	Loch Dhu	..	..
Salop.	Church Stretton ..	2·55	97	,,	Crieff, Strathearn Hyd.	1·49	50
,,	Cheswardine Hall ..	1·62	60	*Perth*	Pitlochry, Fincastle ..	1·55	58
Worcs.	Malvern, Free Library	2·19	96	*Angus*	Montrose, Sunnyside ..	1·96	75
Warwick	Birmingham, Edgbaston	2·77	119	*Aberd.*	Braemar	1·59	62
Leics.	Thornton Reservoir ..	4·63	187	,,	Dyce, Craibstone ..	2·45	81
Lincs.	Boston, Skirbeck ..	2·74	125	,,	Fyvie Castle	2·53	78
,,	Skegness, Marine Gdns.	1·77	81	*Moray*	Gordon Castle	1·70	53
Notts.	Mansfield, Carr Bank ..	3·60	137	*Nairn*	Nairn, Achareidh ..	1·78	70
Derby	Buxton, Terrace Slopes	2·14	54	*Inv's*	Loch Ness, Foyers ..	1.09	36
Ches.	Bidston Observatory ..	1·86	72	,,	Glenquoich	5·25	82
Lancs.	Manchester, Whit. Park	1·76	53	,,	Fort William, Teviot ..	2·32	47
,,	Stonyhurst College ..	3·08	80	,,	Skye, Duntuilm ..	2·11	56
,,	Blackpool	2·58	88	*R. & C.*	Ullapool	1·68	55
Yorks.	Wakefield, Clarence Pk.	3·43	136	,,	Applecross Gardens ..	2·61	65
,,	Hull, Pearson Park ..	1·64	70	,,	Achnashellach	5·08	104
,,	Felixkirk, Mt. St. John	2·35	86	,,	Stornoway Airfield ..	1·39	48
,,	York Museum	2·42	96	*Suth.*	Lairg	..	..
,,	Scarborough	1·37	56	,,	Loch More, Achfary ..	2·55	48
,,	Middlesbrough.. ..	1·36	53	*Caith.*	Wick Airfield	·69	26
,,	Baldersdale, Hury Res.	2·77	87	*Shetland*	Lerwick Observatory ..	1·69	74
Nor'd.	Newcastle, Leazes Pk. ..	1·99	78	*Ferm.*	Crom Castle	3·04	87
,,	Bellingham, High Green	2·18	66	*Armagh*	Armagh Observatory ..	2·73	94
,,	Lilburn Tower Gdns. ..	2·38	96	*Down*	Seaforde	3·07	96
Cumb.	Geltsdale	2·72	79	*Antrim*	Aldergrove Airfield ..	1·67	60
,,	Keswick, High Hill ..	1·91	50	,,	Ballymena, Harryville..	2·15	63
,,	Ravenglass, The Grove	4·12	110	*L'derry*	Garvagh, Moneydig ..	2·24	69
Mon.	Abergavenny Larchfield	·63	25	,,	Londonderry, Creggan	2·49	68
Glam.	Ystalyfera, Wern House	1·76	38	*Tyrone*	Omagh, Edenfel ..	2·56	75

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, MARCH 1949

Stations	Pressure		Temperatures							Relative humidity	Mean cloud amount	Precipitation			Bright Sunshine	
			Absolute		Mean values											
	Mean of day M.S.L.	Diff. from normal	Max.	Min.	Max.	Min.	½ Max. and Min.	Diff. from normal	Wet bulb			Total	Diff. from normal	Days	Daily mean	Percentage of possible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	oktas	in.	in.		hr.	%
London, Kew Observatory	1021·8	+8·9	63	29	48·0	36·1	42·1	−1·0	37·8	77	5·7	0·92	−0·77	8	3·3	28
Gibraltar	1016·2	−0·9	72	48	63·5	54·7	59·1	+1·5	54·6	78	5·5	2·69	—	11	4·8	40
Malta	1015·1	+0·9	71	36	58·7	47·1	52·9	−4·2	50·9	69	4·8	1·71	—	12	7·3	61
St. Helena	1012·9	−1·7	82	60	75·8	63·3	69·5	+4·0	63·7	97	6·7	4·14	+0·02	20	—	—
Lungi, Sierra Leone	1010·1	—	91	71	87·6	75·0	81·3	—	74·3	77	4·5	0·00	—	0	8·1	67
Lagos, Nigeria ..	1009·1	+0·2	96	68	93·2	74·1	83·7	+0·3	78·8	78	6·7	1·84	—	6	5·2	43
Kaduna, Nigeria ..	1006·5	—	99	61	94·7	68·2	81·5	−0·1	64·5	35	3·7	0·27	−0·27	2	8·1	67
Chileka, Nyasaland	1013·4	+0·1	96	60	83·7	66·7	75·2	+1·7	66·9	70	5·0	3·99	−2·60	8	6·0	49
Lusaka, Rhodesia ..	1012·0	−0·1	91	56	81·7	62·1	71·9	+1·6	63·9	81	6·1	4·14	−2·07	10	6·6	54
Salisbury, Rhodesia	1013·4	−0·1	86	51	77·9	58·0	67·9	+0·2	60·3	74	4·8	1·95	−2·75	11	6·3	52
Cape Town	1013·8	−0·7	102	51	81·7	60·6	71·1	+3·0	57·7	59	2·4	0·23	−0·65	3	—	—
Palmietfontein, S. Africa	1016·4	—	82	40	75·5	53·3	64·4	—	56·2	79	4·0	1·94	—	6	7·3	—
Mauritius																
Calcutta, Alipore Obsy.	1009·8	−0·3	99	60	94·2	71·7	82·9	+2·7	72·0	64	1·5	1·28	−0·10	1	8·8	73
Bombay	1010·2	−0·7	99	67	88·8	73·3	81·1	+1·6	71·8	68	1·2	0·00	−0·02	0	8·4	70
Madras	1011·2	+0·3	101	69	92·6	73·0	82·8	+1·7	74·2	75	1·7	0·00	−0·34	0	10·8	90
Colombo, Ceylon ..	1010·5	+0·4	92	70	88·7	74·0	81·3	−0·5	75·1	83	2·3	6·08	+1·80	7	9·6	79
Singapore	1009·7	0·0	94	73	90·1	75·0	82·5	+1·3	76·2	78	4·7	2·91	−4·49	10	—	—
Hongkong	1016·5	+0·5	78	58	70·8	62·6	66·7	+3·4	62·9	84	—	0·17	−2·77	6	2·6	22
Sydney, N.S.W. ..	1017·9	+1·6	82	50	73·8	63·7	68·7	−0·6	64·9	79	5·9	3·80	−1·18	18	4·8	39
Melbourne	1018·0	+1·1	96	46	71·4	55·5	63·5	−1·0	57·9	73	6·1	5·25	+3·07	13	4·4	36
Adelaide	1018·7	+1·6	97	48	77·1	56·4	66·7	−3·2	57·3	49	3·0	0·05	−0·97	2	8·7	71
Perth, W. Australia	1016·1	+0·8	103	52	83·3	60·9	72·1	+0·9			2·4	0·72	−0·09	5		
Coolgardie																
Brisbane	1013·9	−0·5	87	61	80·0	68·1	74·1	−0·2	67·2	68	5·4	7·54	+1·77	21	5·3	43
Hobart, Tasmania	1017·9	+3·7	87	44	66·9	49·1	58·0	−1·3	51·7	64	5·3	1·14	−0·56	7	6·2	50
Wellington, N.Z. ..	1017·9	+1·2	73	41	65·4	51·2	58·3	−1·0	54·4	74	4·8	2·54	−0·79	8	6·9	56
Suva, Fiji	1008·4	0·0	90	72	84·9	74·1	79·5	−0·6	76·6	87	6·4	21·37	+6·88	28	4·6	38
Apia, Samoa ..	1009·2	+0·2	90	72	86·6	74·0	80·3	−0·1	77·4	82	5·9	14·21	+0·50	26	6·3	52
Kingston, Jamaica	1014·3	−0·6	91	65	87·3	69·1	78·2	+1·1	70·5	69	1·4	0·62	−0·40	4	9·0	75
Grenada, W. Indies	—	—	88	70	86·0	72·0	79·0	−1·2	72·0	74	4·0	1·00	−1·66	7	—	—
Toronto	1015·5	−1·8	65	10	39·3	25·6	32·5	+2·9	26·2	73	6·2	2·17	−0·24	15	3·9	33
Winnipeg	1019·4	+0·2	40	−17	24·7	6·9	15·8	+0·8	10·1	99	4·7	0·69	−0·47	6	4·3	36
St. John, N.B. ..	1011·1	−3·0	51	6	37·0	23·8	30·4	+2·0	26·2	84	5·7	4·09	−0·45	20	3·9	33
Victoria, B.C. ..	1015·4	−0·5	57	27	50·3	35·6	42·9	−0·6	37·0	87	5·1	2·22	−0·21	18	4·7	39